APPENDIX H

INFLUENCE OF MINE DRAINAGE ON SEEPAGE TO GROUNDWATER AND SURFACE WATER OUTFLOW

H.1.0 Influence of Mine Drainage on Seepage to Groundwater and Surface Water Outflow

H.1.1. Surface Mines

Mine water discharge from each open pit mine in the Wyoming model area is estimated to be 3.00 m^3/min. Discharge is to natural ephemeral streams which will, in some cases, become perennial as a result of the discharge. Effects of mine drainage on water quality, stream biota, and downstream potable water uses are largely a result of dilution of suspended and dissolved load. The first step in the analysis is to determine what the net outflow of water from the sub-basin will be and then to route this water downstream where contact with man or the food chain is possible. It is assumed that suspended and dissolved chemical loads not leaving the sub-basin because of infiltration and evaporation remain on the stream bed and are available for subsequent transport in flood flows, which are calculated in Section 3.3.3.

Numerous assumptions are made in the analysis to follow, which is patterned after that in NUREG-0511 (Generic Environmental Impact Statement on Uranium Milling), with certain corrections and modifications. The calculations are based on the operation of three surface mines dewatering at a rate of 9.00 m^3/min (3 mines, 3.00 m^3/min each) into a sub-basin of 11.4 km^2 area. This will transform 22.7 kilometers of channel (in the sub-basin and basin) into perennial streams. Note that 7.04 m^3/min will discharge from the sub-basin. The remainder of the flow (1.96 m^3/min) is lost by infiltration and seepage in the sub-basin.

Mine discharge is assumed to enter into a hydrographic area described as follows (Table H.1) and shown in Fig. H.1:

Table H.1 Characteristics of the sub-basin containing the model mines

	Symbol	Value	Units
Slope of region		0.01	%
Substrate hydraulic conductivity (vertical)	K_v	6×10^{-6}	m/min
Substrate hydraulic conductivity (horizontal)	K_h	6×10^{-4}	m/min
Composite hydraulic conductivity	K	6×10^{-5}	m/min
Total outflow of a stream section	Q_T	Calculated	m^3/min
Total loss due to infiltration (seepage) and evaporation	Q_L	Calculated	m^3/min
Seepage loss	Q_s	Calculated	m^3/min
Evaporative loss	Q_e	Calculated	m^3/min
Annual evaporation rate	E	2×10^{-6}	m/min
Length of stream section	L	Variable	m
Reach of stream section with perennial flow	R	Variable	m
Channel dimensions (see Figure H.2)	a,b	Variable	m
Cross sectional area of channel calculated from Q_{in} and V	A	Variable	m^2
Water input from mine drainage	Q_{in}	3.00 per mine	m^3/min
Wetted perimeter of stream bed	B	Variable	m
Velocity of flow	V	36	m/min

$$K = (K_h . K_v)^{1/2}$$
$$= (6 \times 10^{-6} \times 6 \times 10^{-4})^{1/2}$$
$$= 6 \times 10^{-5} \text{ m/min}$$

$$Q_L = (Q_s + Q_e)$$
$$B = a + 2b$$
$$Q_s = KB \times f(L)$$
$$Q_e = Ea \times f(L)$$
$$V = 36 \text{ m/min}$$
$$A = \frac{Q_{in}}{V}$$

Assuming that B and a are dependent only on Q_{in}, V is assumed constant at 36 m/min, and f is a function of L.

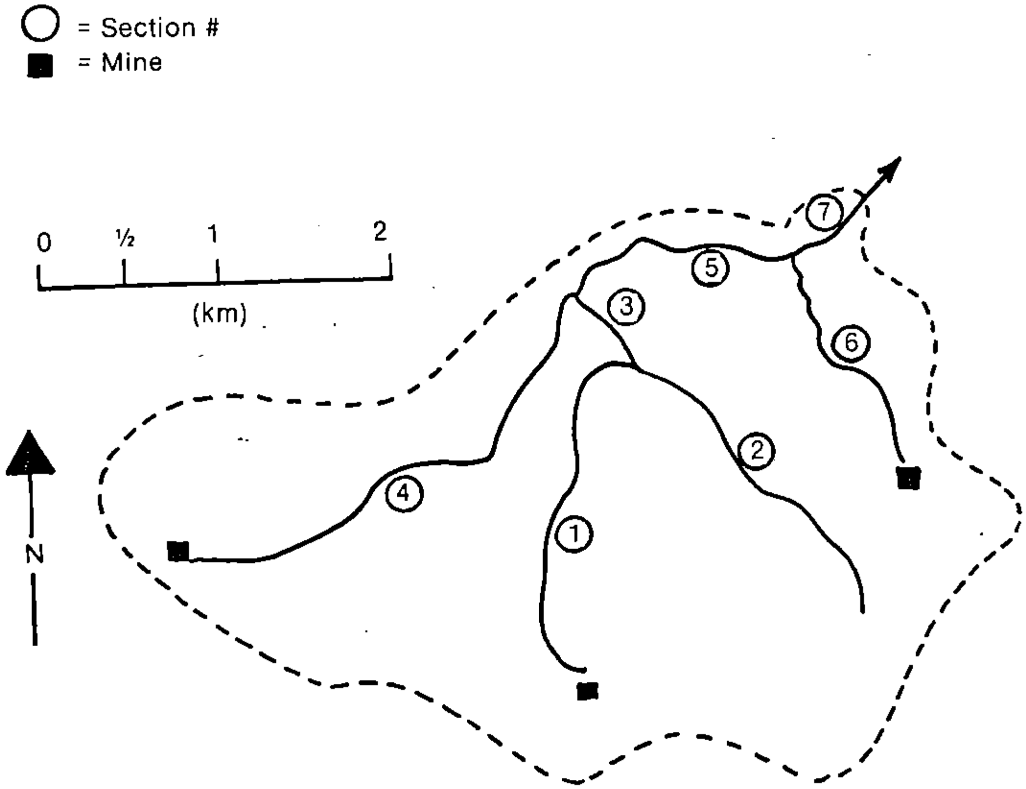

Figure H.1 Wyoming model area sub-basin drainage system

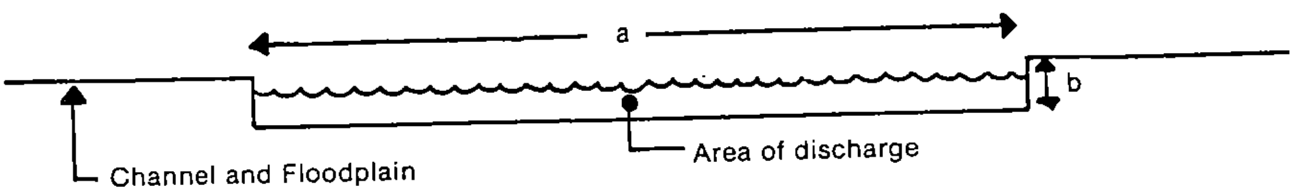

Figure H.2 Model area stream cross section

To find the total outflow (Q_T) from a stream section of length L:

$$\frac{dQ_T}{dL} = -KB - Ea$$

$$\int dQ_T = -(KB + Ea) \int dL$$

$$Q_T = -(KB + Ea)L + C$$

At L = 0, $Q_T = Q_{in}$, so $C = Q_{in}$:

$$Q_T = Q_{in} - (KB + Ea)L$$

To find the total loss (Q_L) associated with a stream of length L:

Since $Q_T = Q_{in} - Q_L$,

$$Q_L = (KB + Ea)L$$

$$A = a \times b$$

Assuming a ratio of b/a = 0.01,

$$a = \left(\frac{Q_{in}}{0.36}\right)^{1/2}$$

$$B = 1.02a$$

so
$$\begin{aligned} Q_L &= (1.02\ K + E)\ aL \\ &= [(1.02\ (6 \times 10^{-5}\ \text{m/min})) + (2 \times 10^{-6}\ \text{m/min})]aL \\ &= (6.32 \times 10^{-5}\ \text{m/min})aL \\ &= (6.32 \times 10^{-5}\ \text{m/min}) \left(\frac{Q_{in}}{0.36}\right)^{1/2} L \end{aligned}$$

To find the reach (R) of perennial stream created by discharge (if there is no net outflow from the section):

If $Q_T = 0$ then $0 = Q_{in} - (KB + Ea)L$

$$L_Q = 0 = R = \left(\frac{Q_{in}}{KB + Ea}\right)$$

Assuming a ratio of b/a = 0.01,

$$a = \left(\frac{Q_{in}}{0.36}\right)^{1/2}$$

$$B = 1.02a$$

$$\text{so } R = \frac{Q_{in}}{(1.02K + E)\left(\frac{Q_{in}}{0.36}\right)^{1/2}} = \frac{(0.36\ Q_{in})^{1/2}}{1.02K + E} = 9493.67 \times Q_{in}^{1/2}$$

The basin drainage channels are assumed to be considerably larger than those of the sub-basin and therefore effect a greater evaporation and seepage loss on the system. Consequently, loss rates due to seepage were doubled, producing the following equations for estimating flows within the basin channels:

$$Q_L = (1.24 \times 10^{-4}\ \text{m/min})\left(\frac{Q_{in}}{0.36}\right)^{1/2}$$

$$R = 4823.15 \times Q_{in}^{1/2}$$

Table H.2 contains the calculations of seepage and evaporation loss and cumulative discharge for the sub-basin and contiguous areas of the basin.

Infiltration of mine discharge to ephemeral streams was not calculated separately but instead was solved as a combined loss for evaporation and infiltration. Both losses are a function of surface area. Infiltration takes place in both the sub-basin and the basin and at different rates. The final calculated infiltration percentage represents a combination of the sub-basin and basin losses, which were calculated separately. When 3 mines are operating, the full reach of perennial stream created is 22.7 km.

Infiltration losses in the sub-basin can be calculated as follows:

$$Q_L = [1.02\ (6 \times 10^{-5}) + (2 \times 10^{-6})]\ aL \qquad \text{(H.1)}$$

where Q_L = flow rate or loss as infiltration plus evaporation, m^3/min

a = width of stream, meters

L = length of stream, meters

Q_s = $6.12 \times 10^{-5} \times aL$

= infiltration loss, m^3/min

Q_e = $2.0 \times 10^{-6} \times aL$

= evaporation loss, m^3/min

Table H.2 *Seepage and outflow calculations for the Wyoming model mine drainage system*

Section Number[(a)]	Section Length L (m)	Q_{in}(3.00 m^3/min per mine)	Total Q_{in} (m^3/min)	Q_L (m^3/min)	$Q_{in} - Q_L$ (m^3/min)	R (m)	Cumulative Discharge (m^3/min)
1	2400	3.00	3.00	0.44	2.56	-	
2	2100	----	----	----	----	-	
3	600	----	2.56	0.10	2.46	-	
4	3000	3.00	3.00	0.55	2.45	-	
5	1400	----	4.91	0.33	4.59	-	
6	1600	3.00	3.00	0.29	2.71	-	
7	900	----	7.30	0.26	7.04	-	7.04
Basin	141000	7.04	7.04	7.04	----	12797	0

(a) See Fig. H.1.

Therefore, $\frac{Q_s}{Q_e} = 30.6$ (H.2)

Since total loss $= Q_s + Q_e = 1.96\ m^3/min$

and $Q_s = Q_e \times 30.6$

then $Q_s = 1.96 - Q_e$ and $Q_e = \frac{1.96}{31.6} = 0.062\ m^3/min$

Then loss due to infiltration in the sub-basin:

$= 1.96 - 0.062$

$= 1.898\ m^3/min$

Infiltration losses in the basin can be calculated as follows:

$Q_L = [1.02\ (1.2 \times 10^{-4}) + (2 + 10^{-6})]\ aL$ (H.3)

where $Q_s = 1.22 \times 10^{-4} \times aL$

$Q_e = 2 \times 10^{-6} \times aL$

Therefore, $\frac{Q_s}{Q_e} = 61.0$ (H.4)

Total Loss $= Q_s + Q_e = 7.04\ m^3/min$

Then loss due to infiltration in the basin:

$= 7.04 - 0.114$

$= 6.926\ m^3/min$

Therefore, total inflow equals 9 m^3/min or $4.73 \times 10^6\ m^3/yr$, and total annual infiltration loss equals $4.65 \times 10^6\ m^3$. Restated, 98.2 percent of the discharge infiltrates and the remainder evaporates.

H.1.2 Underground Mines

Mine water discharge from underground mines in the New Mexico model area averages slightly under 2 m^3/min. Flow characteristics parallel those in the Wyoming model area, as does the methodology applied in calculating the infiltration and evaporation losses and the net outflow. The calculations are based on the operation of 14 mines dewatering at a rate of 28 m^3/min (2.00 m^3/min per mine) into a sub-basin of 246 km^2 area. This will result in transformation of 24.8 km of channel (in the sub-basin only) into perennial streams. Note that there is no discharge from the sub-basin to the basin.

Mine discharge is assumed to enter into a small sub-basin hydrographic unit shown in Figure H.3. The sub-basin characteristics used as model input parameters are the same as those for Wyoming (Table H.1) with the exception of those presented in Table H.3.

Table H.3 Characteristics of the sub-basin hydrographic unit in the model underground uranium mine area

Parameter	Symbol	Value	Units
Substrate hydraulic conductivity (vertical)	K_v	6×10^{-5}	m/min
Substrate hydraulic conductivity (horizontal)	K_h	6×10^{-3}	m/min
Substrate hydraulic conductivity	K	6×10^{-4}	m/min
Annual evaporation rate	E	4.0×10^{-6}	m/min
Water input from mine discharge	Q_{in}	2.00 per mine	m^3/min

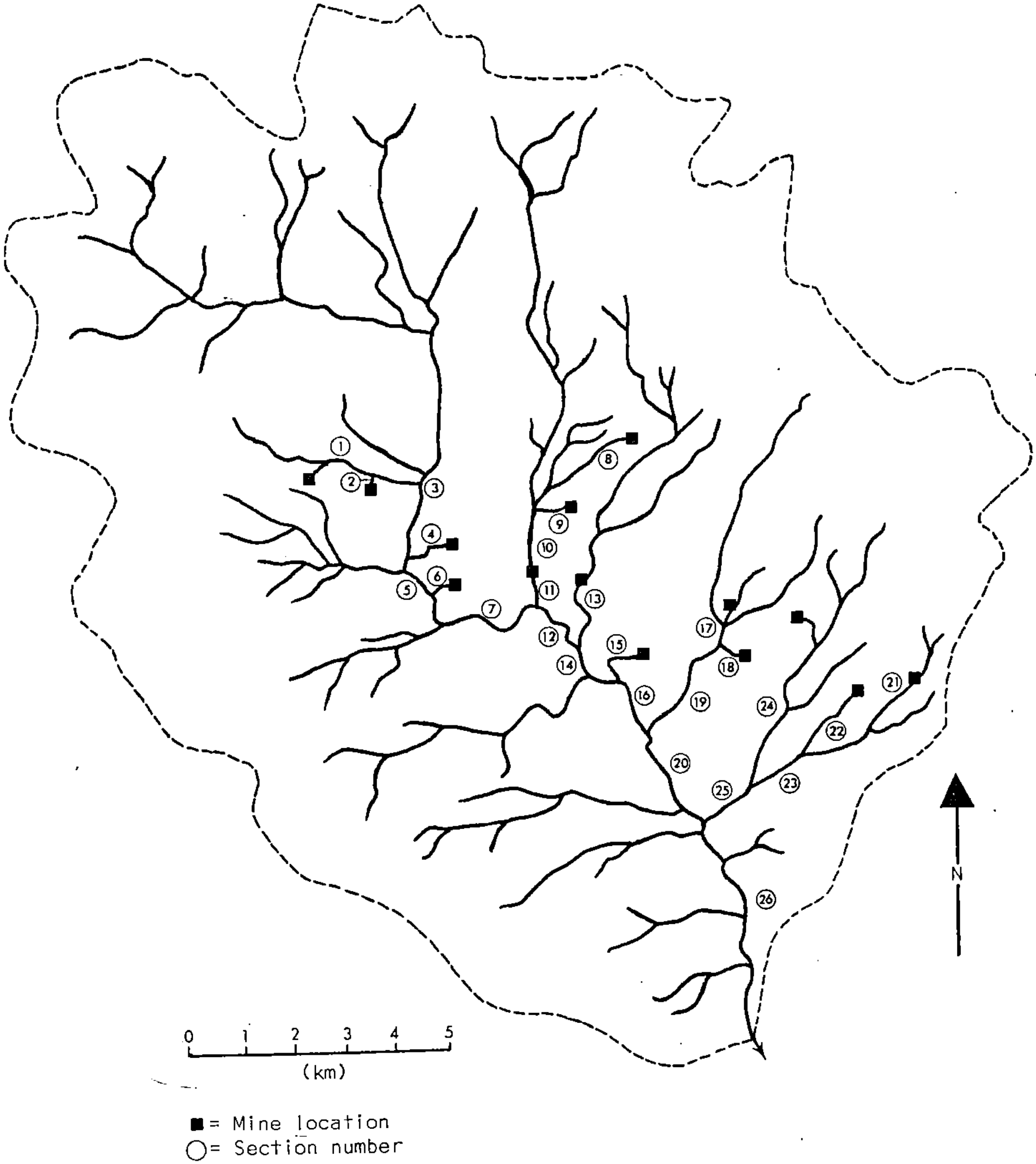

Figure H.3 New Mexico model area sub-basin drainage system

The loss and outflow formulas are of the same format and derivation as the Wyoming equations (see Surface Mines), *but have different final forms due* to the change in infiltration and evaporation rates. The final equations for the New Mexico model area are as follows:

To find the total loss (Q_L) associated with a stream segment of length L:

$$\begin{aligned} Q_L &= (1.02K + E)aL \qquad (H.5) \\ &= [(1.02\ (6 \times 10^{-4}\ m/min)) + (4.0 \times 10^{-6}\ m/min)]\ aL \\ &= (6.16 \times 10^{-4}\ m/min)\ aL \\ &= (6.16 \times 10^{-4}) \left(\frac{Q_{in}}{0.36}\right)^{1/2} L \end{aligned}$$

To find the reach (R) of perennial stream created by discharge (if there is no net outflow from the section):

$$\begin{aligned} R &= \frac{Q_{in}}{(1.02\ K + E)\left(\frac{Q_{in}}{0.36}\right)^{1/2}} \qquad (H.6) \\ &= \frac{(0.36\ Q_{in})^{1/2}}{(1.02\ K + E)} \\ &= 974.03 \times (Q_{in})^{1/2} \end{aligned}$$

Since no net outflow from the sub-basin occurs, equations modified for the basin channel characteristics are not necessary for this model area. Table H.4 presents the calculations of infiltration and evaporation loss and cumulative discharge within the sub-basin.

Infiltration of mine discharge to ephemeral streams was not calculated separately but instead was solved as a combined loss for evaporation and infiltration. Both losses are a function of surface area. Infiltration takes place only in the sub-basin as there is no net outflow. When 14 mines are operating, the full reach of the perennial stream created is 24.8 km.

Infiltration losses can be calculated as follows:

$$Q_L = [(1.02\ (6 \times 10^{-4})) + (4.0 \times 10^{-6})]\ aL \qquad (H.7)$$

Table H.4 Seepage and outflow calculations for the New Mexico model mine area drainage system

Section Number[(a)]	Section Length L(m)	Q_{in} (2.00 m^3/min per mine)	Total Q_{in} (m^3/min)	Q_L (m^3/min)	$Q_{in} - Q_L$ (m^3/min)	R (m)	Cumulative Discharge (m^3/min)
1	1500	2.00	2.00	-	-	1948	
2	200	2.00	2.00	0.29	1.71	-	
3	2300	0	1.71	-	-	1665	
4	1000	2.00	2.00	1.45	0.55	-	
5	800	0	0.55	-	-	534	
6	500	2.00	2.00	0.73	1.27	-	
7	3000	0	1.27	-	-	1241	
8	3400	2.00	2.00	-	-	1948	
9	1000	2.00	2.00	1.45	0.55	-	
10	700	0	0.55	0.53	0.02	-	
11	500	2.00	2.02	0.73	1.29	-	
12	1100	0	1.29	1.28	0.01	-	
13	1500	2.00	2.00	-	-	1948	
14	1400	0	0.01	-	-	10	
15	1200	2.00	2.00	1.74	0.26	-	
16	1100	0	0.26	-	-	251	
17	1000	2.00	2.00	1.45	0.55	-	
18	600	2.00	2.00	0.87	1.13	-	
19	1900	0	1.68	-	-	1635	
20	2100	0	0	-	-	-	
21	3200	2.00	2.00	-	-	1948	
22	2100	2.00	2.00	-	-	1948	
23	1200	0	0	-	-	-	
24	3900	2.00	2.00	-	-	1948	
25	1300	0	0	-	-	-	
26	4900	0	0	-	-	-	0

[(a)] See Fig. H.3.

where Q_L = flow rate or loss as infiltration plus evaporation, m^3/min

a = width of stream, meters

L = length of stream, meters

$Q_s = 6.12 \times 10^{-4} \times aL$

= infiltration loss, m^3/min

$Q_e = 4.0 \times 10^{-6} \times aL$

= evaporation loss, m^3/min

Therefore, $$\frac{Q_s}{Q_e} = 153 \quad \text{(H.8)}$$

Since total loss = $Q_s + Q_e = 28\ m^3/min$

and $Q_s = Q_e \times 153$

then $Q_s = 28 - Q_e$ and $Q_e = \frac{28}{154} = 0.18\ m^3/min$

Then loss due to infiltration in the sub-basin:

= 28 - 0.18

= 27.82 m^3/min

Therefore, total inflow equals 28.0 m^3/min or $1.47 \times 10^7\ m^3/yr$, and total annual infiltration loss equals $1.46 \times 10^7\ m^3$. Restated, 99.3 percent of the discharge infiltrates and the remainder evaporates.